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JUN 8 1980

Jun 1979

Topical Report,

MODEL TESTS OF MISSILE WITH HARD LINK,

By: R. E. Emerson

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FEB 11 1980

Prepared for:

DEPARTMENT OF THE ARMY
Attention: L. McConnell
U.S. Army Armament R & D Command
Dover, New Jersey 07801

Approved:

J. D. Colton

J. D. Colton, Project Supervisor
Engineering Mechanics Group

G. R. Abrahamson, Director
Poulter Laboratory

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BACKGROUND AND OBJECTIVES

The U.S. Army Armament R&D Command (ARRADCOM) is developing a
hard-link safe-arm system to improve the safety of a nuclear munition
during accidental impact. To show that this device responds as desired
under impact conditions, full-scale sled tests are being performed.
In the full-scale tests an actual missile structure, including a mock
warhead and the shipping container, is accelerated in the axial direction
so that the aft end impacts a rigid barrier. The objectives of the full-
scale tests are to determine whether or not the hardened cable between
the warhead and the hard link is severed, particularly at the shear
connection at the warhead, and to determine the type and severity of
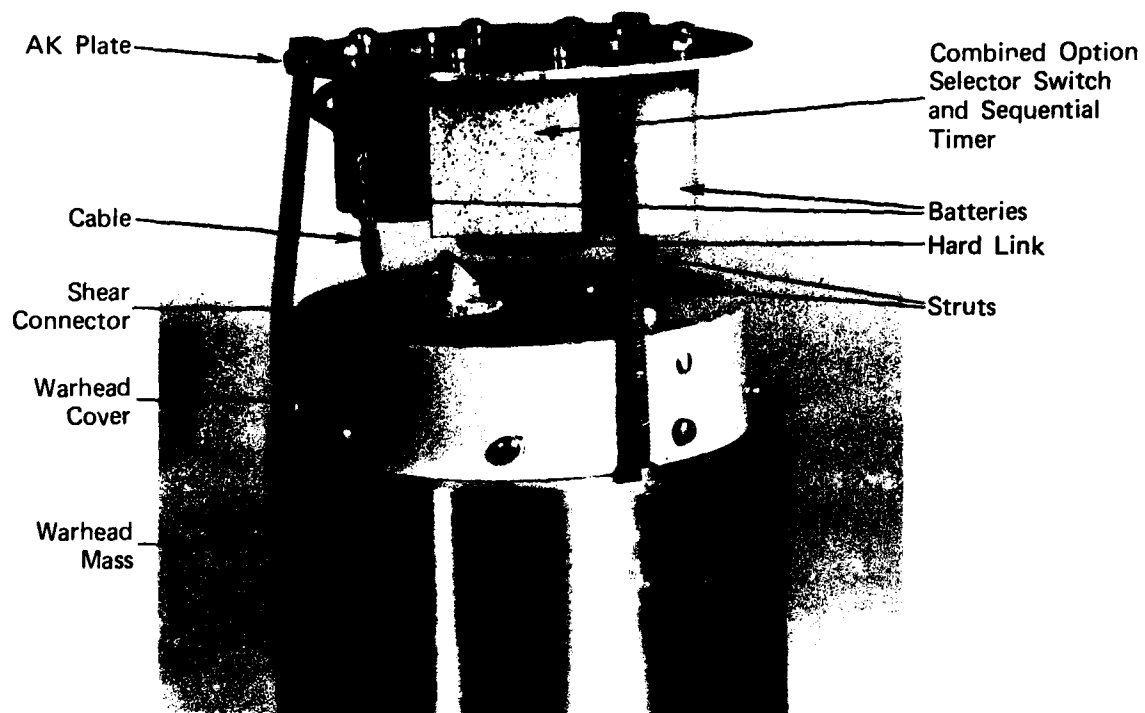damage sustained by the hard link during the impact.

Six scale-model impact tests were conducted at SRI with the overall
objectives of helping to plan the full-scale tests and to extrapolate
the results of the full-scale tests to impacts at lower and higher
velocities. The axial impact tests were conducted on scale-model
adapation kits consisting of several components and a model warhead.
The specific objectives of the model tests were to:

(1) Determine the dynamics of the impact, that is, the
relative motion of the warhead, AK components, and
the hardened cable.

(2) Determine the mode of response of the cable, possible
mechanisms that may lead to cable damage, and whether
or not the connector between the cable and warhead
cover is severed during the impact.

SCALE-MODEL IMPACT TESTS

Scale Model of Missile Section. The model structures were fabri-
cated in 2/9-scale (4-inch-diameter mock warhead) and consist of idealized
models of the missile elements. Figure 1 shows one of the models before
testing. The wall structure of the missile--and, in aft impacts, the
shipping container--absorb very little of the kinetic energy at the

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AK Plate

Cable

Shear
Connector

Warhead
Cover

Warhead
Mass

Combined Option
Selector Switch
and Sequential
Timer

Batteries

Hard Link

Struts

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FIGURE 1   SCALE MODEL OF MISSILE SECTION

impact velocities of interest. Therefore the shipping container and missile wall are not included in the model. Deleting the missile wall and container allowed us to take high-speed movies of the internal component dynamics during the impact.

In the scale model, the following components are fabricated as deformable structural elements: the cable and cable connection, the warhead aft covers, and the AK mounting plate. Rigid masses are used to model the remaining elements, such as the warhead, batteries, arm-safe device, hard link, combined option selector switch, and sequential timer. (The combined option selector switch and sequential timer are modeled as a single mass; in early tests the arm-safe device and hard link are modeled as a single mass, but in later tests they are modeled as separate masses as discussed below.) In addition, several components located under the warhead covers were modeled as rigid elements (not visible in Figure 1).

A key element in the hard-link safe-arm system is the connection between the hardened cable and the warhead. The connector consists of two parts held together by three shear pins and is designed to fail in shear along a plane perpendicular to the axis of the missile. The specified torque that causes the connector to fail is 32 ft-lb. From this value we derived the corresponding load needed to fail the shear pins in unidirectional shear; it was 440 lb. The connector was modeled in the scale model by two disks with three pairs of holes (the disks resemble buttons). The two disks were held together by 0.010-inch-diameter copper wire, which is laced through the holes.

To ensure that the scale-model connector accurately models the full-scale connector, we conducted tests on scale model connectors identical to those used in the model tests. The average of the measured loads (scaled to full-scale values) required to fail the model connector in three tests of each type were 37 ft-lb in torsion and 425 lb in unidirectional shear. The variation of the measured values was less than ±10%.

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In four of the impact tests (Test 3, 4, 5, and 6), the hard link and the arm-safe device were modeled by two rigid elements held together by a weak adhesive. The upper section, which models the hard link, separates from the lower one, which models the arm-safe device, when a 50-lb shear force is applied. This low-force breakaway represents the failure on impact of the brittle cast aluminum pedestal of the full-scale hard link.

The warhead and AK are positioned relative to each other by struts, shown in Figure 1. The struts are threaded brass rods and are shaped to buckle outward on impact, thereby absorbing minimal energy. In Tests 1 through 5, 0.164-inch-diameter rods were used. A force of 500 lb is needed to collapse the struts. An upper bound on the energy absorbed by the struts on impact is 42 ft-lb. This value is an upper bound because it is the product of the maximum measured collapse force and the maximum displacement of the struts. This upper bound is equal to about 40% of the kinetic energy of the model warhead at 50 ft/sec and less than 5% of warhead kinetic energy at 150 ft/sec.[*] In Test 6, 0.190-inch-diameter struts were used. The force needed to collapse these struts is 1150 lb, and an upper bound on the energy absorbed by the struts is 97 ft-lb. This upper bound is less than 3% of the warhead kinetic energy at the 290 ft/sec velocity used in Test 6.

Impact Tests. The models were accelerated in a 3-ft-long, 4-inch-diameter gas gun. At the breech end of the gun, several ports connect the gun barrel to a pressurized gas reservoir. When the ports open, gas flows into the barrel and accelerates the model to the impact speed. After leaving the gun, the models impact a 400-lb rigid steel barrier 18 inches from the muzzle end of the barrel.

High-speed movies were taken from the side to view the dynamics of the missile components during the impact. The missile was oriented so that the cable and cable connector were in view. The nominal camera speed was 10,000 frames per second.

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[*] No measurable change in velocity occurred during collapse of the struts in any of the tests.

Six scale-model axial impact tests were conducted. The impact velocity for each test is given below.
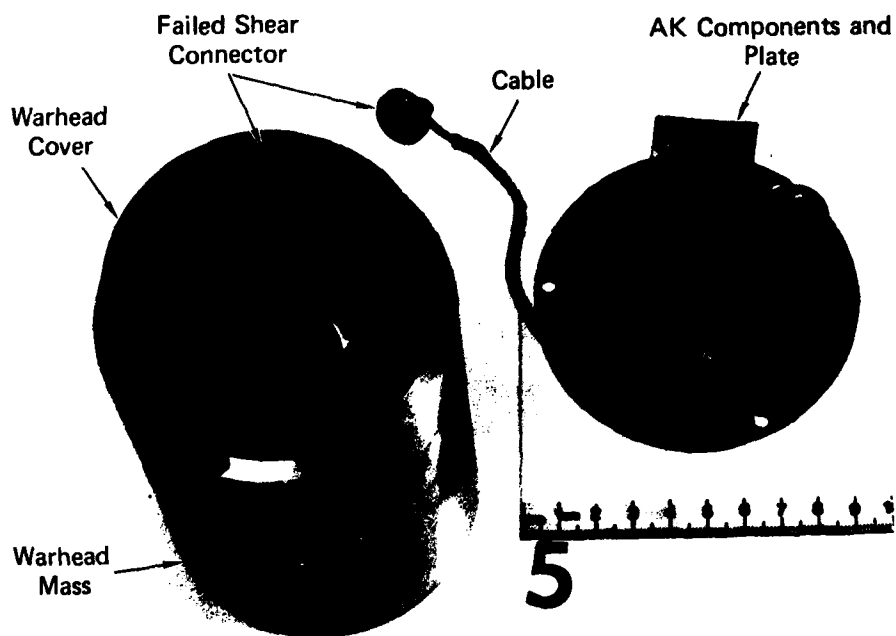
Test No.	Impact Velocity* (ft/sec)
1	100
2	70
3	150
4	125
5	50
6	290

The times and sequence of events determined from the movie of Test 5 (50 ft/sec) are as follows. The AK plate impacts the rigid barrier, and the plate and AK components stop. The brass struts collapse and fracture as the model warhead continues to move toward the barrier with no measurable change in velocity. Approximately 300 µsec after the AK contacts the barrier, the cable connector impacts the combined selector switch-sequential timer component model. As the warhead continues to move toward the barrier, the connector begins to penetrate the warhead cover and fails in shear. The warhead cover deforms and fractures as the warhead mass pushes it into the AK components. This crushing continues for about 1500 µsec after the initial barrier contact until the gap between the cover and the warhead mass is closed. The warhead then decelerates in about 400 µsec. The warhead and AK rebound from the barrier at a low velocity.

Figure 2 shows the damage to the model from Test 5. (The AK plate and components have been positioned so that the forward end of the components is shown in the photograph). The two parts of the shear connector have separated and the cable is intact. The two parts of the

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*We estimate that these values are accurate to ±3%. These velocities were determined from velocity pins that the projectile contacted as it left the gas gun, from high-speed films of the tests, or, in Tests 5 and 6, from the interruption of laser beams by the projectile before impact.

FIGURE 2   MISSILE MODEL DAMAGED IN TEST 5 (50 ft/sec)
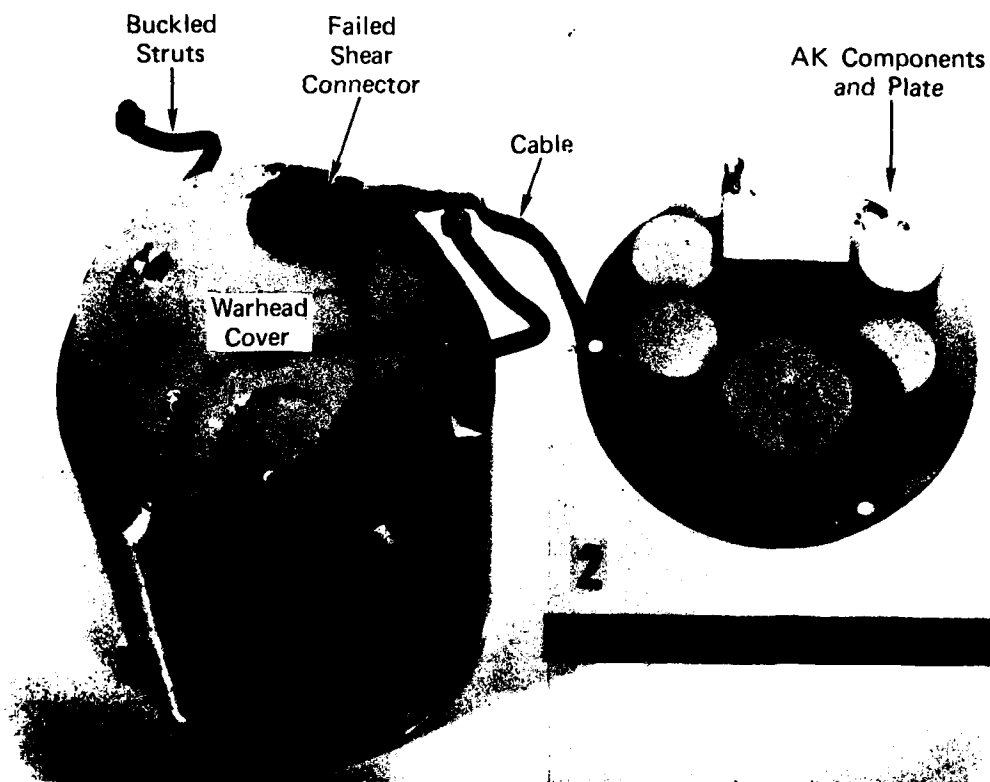
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hard-link model, which were held together by a weak adhesive, did not separate. The AK components are deformed only slightly.

The dynamics of Test 2 (70-ft/sec impact velocity) and Test 1 (100-ft/sec impact velocity) were very similar to those of Test 5. Figure 3 shows the damage to the model from Test 2. The failed shear connector is embedded in the warhead cover, and the cable between the connector and the hard link is intact. Fractures in the warhead cover can be seen. The damaged model from Test 1 is shown in Figure 4. The relative displacement of the two parts of the shear connector is greater than in Test 2, and the warhead cover is more severely deformed. Also, one of the model components under the warhead cover made a deep dent in the model of the hard link. In Tests 1 and 2, the brass struts did not fracture.

The dynamics of Tests 3, 4, and 6 (higher velocities) differ in several ways from those of Tests 1, 2, and 5 (lower velocities). First, in Tests 3, 4, and 6 the two-piece model of the hard link was used and the pieces separated. It was not possible to tell from the film when this occurred. In Tests 1 and 2 a single-piece model of the hard link was used, and in Test 5 a two-piece model was used. As mentioned previously, the two pieces did not separate in Test 5 (50 ft/sec).
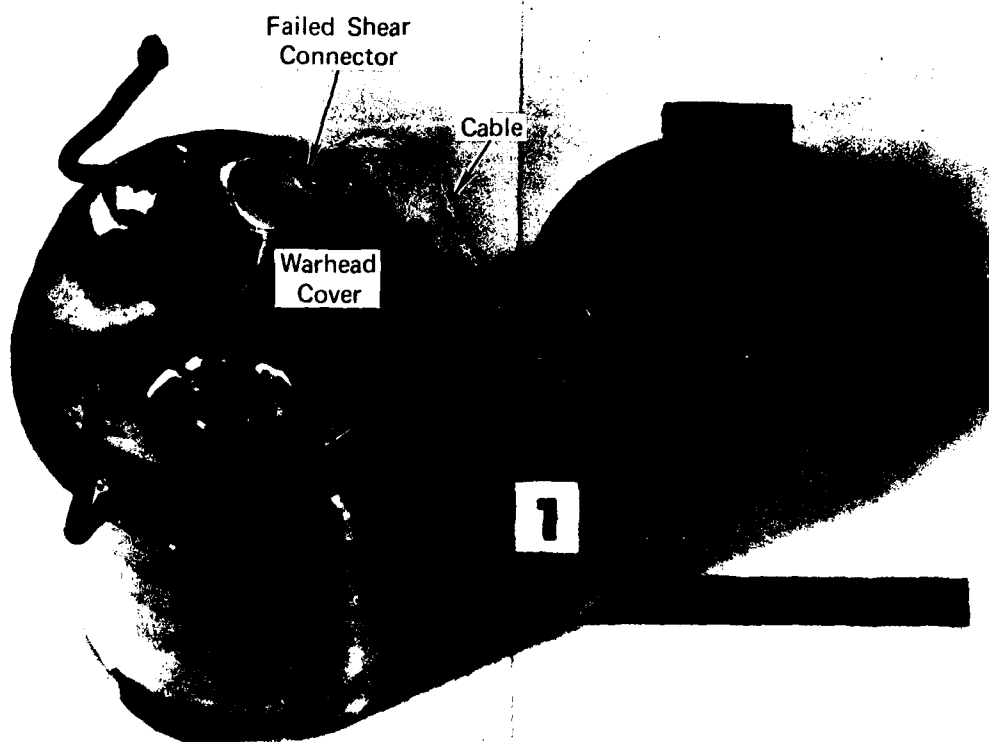
Second, the cable was severed from the cable connector in Tests 3, 4, and 6. This may be caused solely by the higher impact velocity or by the dynamic loads imposed by the freely moving hard-link mass attached to the other end of the cable. Also in Tests 3 through 6 the brass struts fractured during the impact. However, we think these fractures did not have an appreciable effect on the dynamics of the model before the model rebounded from the barrier.

The damaged models from Tests 4, 3, and 6 are shown in Figures 5, 6, and 7, respectively. The severed cable and the separated hard-link pieces are visible. In Test 4, the part of the cable connector attached to the cable remained embedded in the warhead cover. In Tests 3 and 6, however, this part separated from the cover completely. In Test 6, the deformation of the AK components was severe. The warhead cover fractured
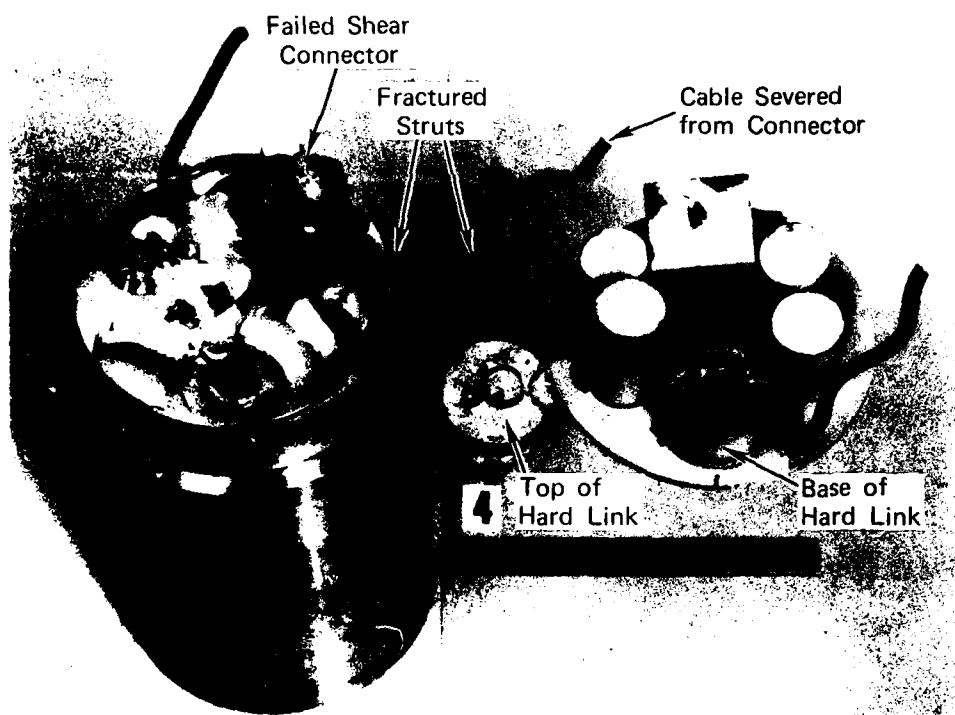
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Buckled Struts · Failed Shear Connector · Cable · AK Components and Plate · Warhead Cover

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FIGURE 3   MISSILE MODEL DAMAGED IN TEST 2 (70 ft/sec)

Failed Shear
Connector

Cable

Warhead
Cover

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FIGURE 4   MISSILE MODEL DAMAGED IN TEST 1 (100 ft/sec)

Failed Shear
Connector

Fractured
Struts

Cable Severed
from Connector

Top of
Hard Link

Base of
Hard Link

MP-7422-5

FIGURE 5   MISSILE MODEL DAMAGED IN TEST 4 (125 ft/sec)

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Failed Shear
Connector

Cable Severed
from Connector

Top of
Hard Link

Base of
Hard Link

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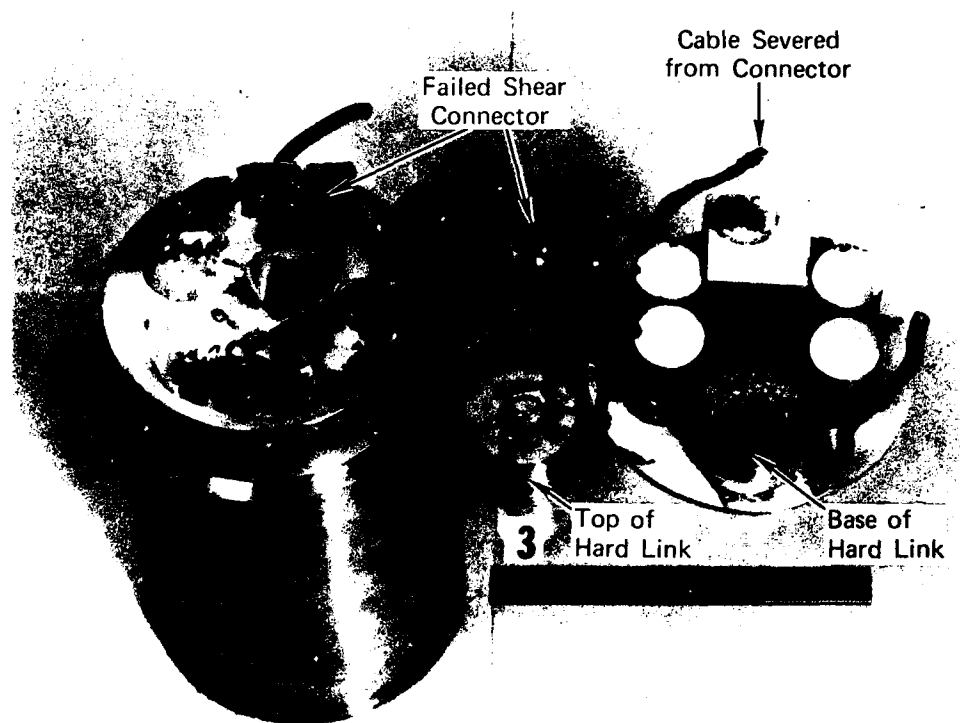
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FIGURE 6   MISSILE MODEL DAMAGED IN TEST 3 (150 ft/sec)

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Sections of Warhead Cover
Failed Shear Connector
Warhead Mass
Base of Hard Link
Top of Hard Link
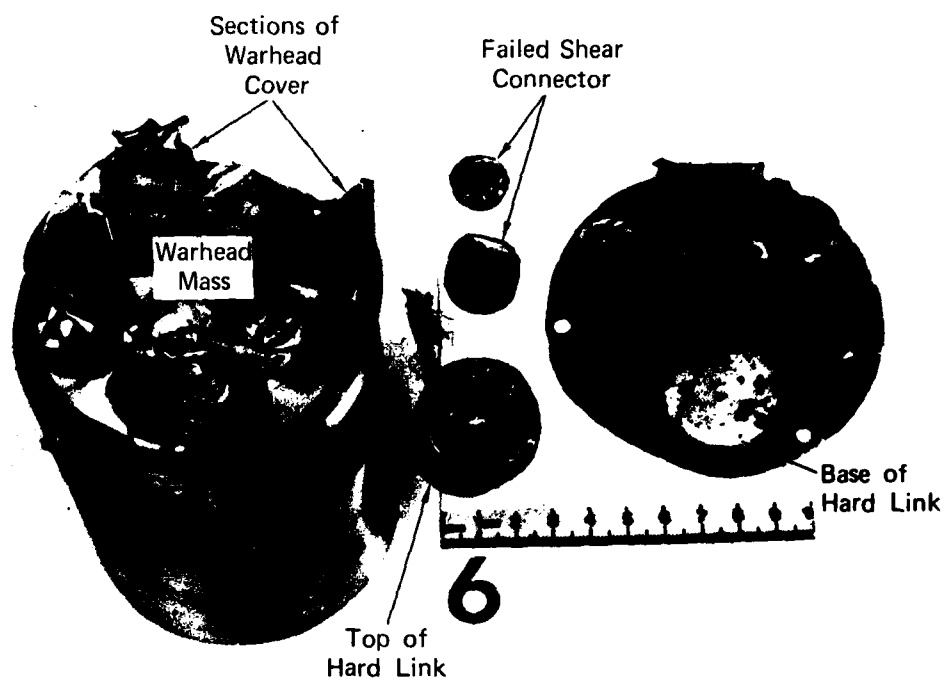
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FIGURE 7   MISSILE MODEL DAMAGED IN TEST 6 (290 ft/sec)

into several pieces and the model of the hard link absorbed enough energy to be hot after the test.

CONCLUSIONS

Three conclusions can be drawn from the results of the six impact tests that were conducted using scale models. Because the AK components were modeled as rigid elements and the shape of the warhead was simplified considerably, these conclusions should be regarded as indications of what to expect in the full-scale tests, not as quantitative predictions of velocity-damage relationships.

First, the shear connector failed, as it was designed to, even at the lowest impact velocity. Although the initial impact velocity of the connector and the AK component is normal to the shear plane of the connector, transverse loads great enough to fail the shear pins are generated as the connector is pushed into the cover.

Second, the cable may be damaged in the tests. At the three higher speeds, the cable was severed. Although the strength of the cable was not specifically modeled, steel braided cable similar to the prototype hardened cable was used in the model test. From the model tests, we conclude that sufficient loads may be generated in the impact to cause substantial damage to the cable.

Third, damage to the AK in a 300-ft/sec impact will be severe. The rigid models of the AK components deformed plastically, indicating that the weaker full-scale components will also be severely deformed.